Edmund C. Berkeley as a Popularizer and an Educator of Computers and Symbolic Logic*

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Abstract

This paper explores how Edmund C. Berkeley tried to instruct and popularize high-speed computers in the 1940s and 1950s and how Berkeley emphasized the connection between computers and symbolic logic. Berkeley strengthened his conviction in the significance of symbolic logic and Boolean algebra before his graduation from Harvard University and maintained this conviction for more than 30 years. Berkeley published books and articles, including *Giant Brains*, and sold electrical toy kits by which young boys could learn electrical circuits and their logical implications. The target audience of Berkeley covered wide range of people including those who were not making computers but were interested in using them, that is, amateur adult technology enthusiasts who enjoyed tinkering with technology or reading about science and technology, and young students. In these projects Berkeley used Shannon's paper of 1938, "A symbolic analysis of relay and switching circuits" as a theoretical basis of his conviction. Design of these kits was fine-tuned by Claude E. Shannon.

Key words: Edmund C. Berkeley, symbolic logic, computer, Claude E. Shannon, *Giant Brains*

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1. Introduction

This paper describes how Edmund C. Berkeley, since the 1940s and in a career spanning over twenty years, aspired to popularize and educate the public about the connection between symbolic logic and the structure of computing machinery. Berkeley was one of the founders and the first secretary of the Association for Computing Machinery (ACM), the world's largest society for computing and his contributions to the ACM have been widely discussed.[1] Unlike the other founders and primary figures of the ACM at that time,

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[1] Berkeley's activity in ACM can be found in Atsushi Akera, "Edmund Berkeley and the Origins of ACM," *Communications of the ACM*, vol. 50 no. 5 (May 2007), pp. 30–35, and Jim Adams, "Edmund C. Berkeley: ACM Founder," *Communications of the ACM*, vol. 31 no. 6 (June 1988), pp. 781–782.

Berkley maintained a singular position within the computer community: he was neither a computer builder nor a computer designer. Although he had a number of acquaintances in the community, he did not play a pivotal role in the design and construction of the advanced high-speed computing machines built after WWII. He concentrated his efforts on establishing the field of computer machinery and on educating the public about the new high-speed computing machines. As a result, he formulated a discourse that indicated the purpose of and the most remarkable characteristics of this new machinery. In particular, Berkeley's activities were influenced by his belief in the importance of symbolic logic and Boolean algebra. Berkeley's target audience covered a wide range of people, including those who were not computer builders but were interested in using computer machinery (i.e. amateur adult technology enthusiasts who enjoyed tinkering with technology or reading about science and technology) and young students. Berkeley devised various projects that matched the interest of each target group.

This paper will first explore how Berkeley reinforced his ideas about the application of symbolic logic and Boolean algebra. Then, it will explain what Berkeley learned from the new high-speed computing machines built in the late 1930s and early 1940s, such as the Complex Number Calculator from Bell Telephone Laboratories and Harvard Mark I and II. Finally, the paper will focus on Berkeley's plans to popularize symbolic logic and electrical large-scale computers in the form of books, articles, and the toy kits sold by his own firm, as well as his collaborative work with Claude Shannon. His extensive distribution of his personal interpretation of Shannon's 1938 paper to his readers and customers via this new media will also be demonstrated.

2. Berkeley and Symbolic Logic

Berkeley realized the importance of mathematical logic when studying mathematics as an undergraduate student at Harvard University. He recognized the value of "the methods of rigorous thinking"[2] backed up by logic, and believed that logic was the essential guide leading humans to rational and reasonable action. As Berkeley stated in the Harvard Commencement of June 1930, "[t]he growing complexity and interdependence of the social, economic, and political forces of the whole civilized world make precision reasoning necessary"[3] and "precision reasoning" should be created using logic. Above all, symbolic logic and the Boolean algebra used for precise reasoning fascinated Berkeley and continued to capture his attention even after his graduation.[4]

After passing his professional actuarial examinations, Berkeley worked at Mutual Life Insurance as an actuarial clerk for four years, and in 1934, he joined Prudential Insurance.

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[2] Edmund C. Berkeley, "Modern Methods of Thinking," June 19, 1930. Box 79, Folder 7, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

[3] Ibid.

[4] Edmund C. Berkeley, "Memorandum for John Wiley and Sons from Edmund C. Berkeley," July 22, 1949. Box 8, Folder 32, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis. Berkeley's "method of thinking" and the intellectual climate in the 1920s and the 1930s can be found in Bernadette Longo, "Edmund Berkeley, Computers, and Modern Methods of Thinking," *IEEE Annals of the History of Computing* (October–December 2004), pp. 4–18.

In 1939, he obtained an assistant mathematician position ad worked not only as an actuary but also on computing costs and allowances in policy changes.[5] By 1942, Berkeley familiarized himself with the punch-card system used in the Methods Department of Prudential. At the company, in addition to IBM machines, special types of punch-card machines had been developed and used for statistical processing since the late nineteenth century.[6] Berkeley carried out research on the application of symbolic logic to these machines when used in insurance companies. He applied Boolean algebra to IBM electrical punch-card machines as an attempt to cope with the problems in tabulating the conditions of insurance contracts. Berkeley confidently believed that Boolean algebra was "full of potentialities," and he anticipated that with Boolean algebra, it would be easy and possible to reason out clauses and manipulate conditions.[7]

Berkeley also felt that Boolean algebra had not yet been fully utilized and that the resulting useful knowledge derived from the combination of symbolic logic and Boolean algebra was "waiting for a popularize."[8] Berkeley obviously decided to take upon himself the popularizer, and for over twenty years, was driven by this sense of a mission.

3. Berkeley and Computing Machines

Berkeley first learned about the new high-speed computing machines in 1939 through his visit of Bell Labs that had the Complex Number Calculator.[9] The calculator, developed by George Stibitz and S. B. Williams, was one of the earliest high-speed, large-scale computing machines built at Bell Telephone Laboratories. The first development of computing machinery was initiated by Stibitz and Williams in the late 1930s. Stibitz contrived an adding mechanism using relays and commonly used parts for telephone switching systems in Bell Labs in October 1937. The following year, in collaboration with Williams—a skilled switching engineer—he began developing it into a large calculator and they completed its description and figures in 1939.[10] Stibitz designed this high-speed relay machine to be a new device that calculated complex numbers for the electrical network design within the telephone exchange system. In Bell Labs, calculations had previously been carried out by humans using hand-operated ordinary commercial calculators, but it would be "[a] slow and complicated [process], require intermediate numbers to be read from the machine and recorded for subsequent use, and thus [would] make errors of transcription difficult to

[5] Edmund C. Berkeley, "Record of Edmund Callis Berkeley," June 4, 1949. Box 8, Folder 32, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

[6] Charles Eames and Ray Eames, *A Computer Perspective* (Harvard University Press, 1990), p. 31.

[7] Edmund C. Berkeley, "Boolean Algebra Problems," January 25, 1937, Handwritten Memorandum. Box 1, Folder 21, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

[8] Edmund C. Berkeley, "Boolean Algebra (The Technique for Manipulating "AND," "OR," "NOT," and Conditions) and Applications to Insurance," *The Record of the American Institute of Actuaries*, vol. XXVI, part II, no. 54, October, 1937, pp. 373–414, and vol. XXVII, part I, no. 55, June, 1938, pp. 167–176, reprinted January 1952. Box 68, Folder 1, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

[9] Bernadette Longo, op.cit., p. 9.

[10] George R. Stibitz, "History of Relay Computation for Patent Dept." Box 2, George R. Stibitz Papers, Dartmouth College Library.

avoid."[11] The Complex Number Calculator was three-times faster than the previous hand-operated calculator, and operators simply needed to correctly input the problems. This calculator gained its remarkable reputation at a demonstration at the meeting of the American Mathematical Society in Hanover, New Hampshire, in September 1940.

Berkeley revisited Bell Labs in late July 1941 to observe the Complex Number Calculator. Apparently, it was "hardly a part of [the] application of symbolic logic," but Berkeley drew a parallel between it and the IBM punch-card machines used at Prudential. He realized that, although complex numbers seemed to have nothing to do with insurance company problems, the "branch of mathematics of logic" could be used to find solutions to insurance problems, for instance, to organize the punch-card system in the company.[12] Berkeley sent a report about the calculator to Stibitz, and the latter was impressed by the detailed description.[13] In September 1941, Berkeley invited Stibitz and other Bell Labs engineers to Prudential and held discussion on the possibility of applying Bell Labs' electric relay computers to the "calculation of insurance company tables and individual policy calculations".[14] On the basis of Berkeley's idea to introduce a relay calculator into the company, Bell Labs' engineers suggested the necessity of adding a function of to compare two numbers and create tables, since the Complex Number Calculator was not designed to perform sorting or reasoning. The meeting concluded with an expectation of favorable prospects and another discussion was held in November of the same year. However, a detailed plan was not devised because Stibitz was called to work for the National Defense Research Committee, and the Circuit Construction Department of Bell Labs became engaged in national defense work;[15] therefore, the development of calculators for insurance companies "could not be undertaken by the Laboratories until after the war emergency was over."[16] The discussion was reopened in March 1945, in view of "the recent development of the ballistic computers and of the present development of the all-purpose computer."[17] In this meeting, Stibitz, Williams and Harry Nyquist from Bell Labs and Berkeley and E. F. Cooley from Prudential suggested the creation of the all-purpose computer X-66744, which was the Model V relay computer and successor to the Complex Number Calculator. This computer could "be modified to meet their requirements" and "a reasonable estimate of $500,000 would cover the production of the equipment and the development of such modifications," however, they concluded that nothing could be done until the end

[11] George R. Stibitz, "Stibitz, Memo for Relay Computer," August 26, 1940, p. 2. Box 1, Folder "History 1940", George R. Stibitz Papers, Dartmouth College Library.

[12] Edmund C. Berkeley, "Analysis of the Operation of the Complex Computer, a Machine Developed by the Bell Telephone Laboratories," Application of Symbolic Logic Report No. 3, August 3, 1941, p. 5. Box 2, Folder 18, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

[13] George R. Stibitz, Letter from Stibitz to Berkeley, September 24, 1941. Box 1, Folder 47, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

[14] Edmund C. Berkeley, "Electrical Relay Computing Machine for Insurance Company Calculations: Application of Symbolic Logic Report No. 6," October 8, 1941. Box 2, George R. Stibitz Papers, Dartmouth College Library.

[15] Ibid. p. 2.

[16] S. B. Williams, Conference Notes, March 7, 1945, p. 1. Box 2, George R. Stibitz Papers, Dartmouth College Library.

[17] Ibid. p. 1.

of the war.[18] Eventually, Prudential never introduced the computing machines from Bell Labs for several reasons: Bell Labs was not active in constructing relay calculators and did not decide its attitude on the calculators[19] and Stibitz resigned from Bell Labs in 1945. In 1947, Berkeley considered introducing a computing machine developed by the Eckert Mauchly Computer Corporation,[20] and Prudential agreed to sign a consulting contract with John Mauchly.[21]

From December 1942 to July 1946, Berkeley temporarily left Prudential to work for the U. S. Naval Reserve on active duty.[22] He worked at the Harvard Computation Laboratory under Howard Aiken and was involved in a project on a new type of high-speed relay calculators known as Harvard Mark I and Mark II. Berkeley worked on preparing program tapes for Harvard Mark I and helped in the design of the Mark II. Through this experience, he became acquainted himself with computer scientists, deepened his knowledge of newly developed computing machinery, and became convinced that the new computing machines had a significantly larger power of computing than the old calculating machines and IBM punch-card machines. His experience in the U. S. Naval Reserve helped him to apply "modern technology" to solve company problems, such as the use of the electronic facsimile copying machine, microfilm selector, and automatic sequence-controlled calculators.[23] Soon after he began working at the Harvard Computation Laboratory in 1945, Berkeley understood the possibility of applying high-speed computers to perform not only numerical but also logical operations. Berkeley "realized that these mechanical brains would have no difficulty with any symbolism, and could do not only numerical operations but also logical ones to the fullest extent necessary."[24]

Through his experience at Bell Labs and the Harvard Computation Laboratory, his acute interest in symbolic logic and new interest in high-speed calculators were united. Berkeley was convinced that these new high-speed computing machines could have a significant impact on society and that the computing machine industry had immense possibilities. This conviction later influenced Berkeley to establish his own firm—Edmund C. Berkeley and Associates—for the purpose of developing a technical service in fields

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[18] Ibid. p. 2.

[19] Edmund C. Berkeley, "Analysis of the Operation of the Complex Computer, a Machine Developed by the Bell Telephone Laboratories: Application of Symbolic Logic Report No. 3," August 3, 1941, p. 1. Box 2, Folder 18, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis. Bell Labs had been reluctant to construct calculators, because Bell Labs was not willing to pay for projects which were not associated with telephony (Letter from Shannon to Rippenbein, April 11, 1949. Box 1, Folder 3, Papers of Claude Elwood Shannon (MSS 84831), Library of Congress. and John R. Pierce, "Interview with John Robinson Pierce, Pasadena, California, November 1979," by Harriett Lyle. California Institute of Technology Oral History Project. (http://oralhistories.library.caltech.edu/98/), viewed October 31, 2012).

[20] John W. Mauchly, Letter from Mauchly to Berkeley, March 28, 1947. Box 3, Folder 61, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

[21] Martin Campbell-Kelly and William Aspray, *Computer: A History of the Information Machine*, second edition, (Westview Press, 2004), pp. 97–98. For details on the introduction of computing machines to Prudential by Berkeley, see Bernadette Longo, op.cit.

[22] Edmund C. Berkeley, "Record of Edmund Callis Berkeley," June 4, 1949. Box 8, Folder 32, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

[23] Ibid.

[24] Edmund C. Berkeley, "Memorandum for John Wiley and Sons from Edmund C. Berkeley," July 22, 1949. Box 8, Folder 32, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

such as "business methods and clerical procedures for handling information," "machinery for handling information," "actuarial and mathematical information and methods" and the "new application of scientific research and modern technology."[25] After returning to Prudential in 1946, Berkeley worked as a methods analyst and was later assigned the position of chief research consultant, but by the winter of 1946, he also began considering the idea of establishing his own firm.

In addition to conceptualizing what his firm would like, he helped organizing people in the field of computing machinery. In January 1947, the first symposium on "Large Scale Calculating Machinery" held at the Harvard Computation Laboratory. On the third day of the symposium, Samuel Caldwell of the Massachusetts Institute of Technology (MIT) suggested "an association of those who were interested in the new field of automatic computing machinery." In May of the same year, "Temporary Committee for an Eastern Association for Computing Machinery" was formed. Berkeley helped organize this association,[26] and in the fall of 1947, the term "Eastern" was dropped, and the name of the association became the Association for Computing Machinery.[27] The target audience of the ACM's activities was scholars, engineers, and firms and companies dealing with computer machinery.

On the other hand, through his own firm, Berkeley intended to promote the education and popularization of the use of computing machinery among the public, including those who were not directly working with and who had limited knowledge about this technology. Berkeley set himself a wide target audience. One category comprised those interested in computing machines; this category could be divided into two groups: those who actually built the machines and those who were enthusiastic about using the machines. Some people who worked within the field of computer machinery were already aware of such a grouping. For example, in a paper submitted at the 1949 ACM meeting held in Oak Ridge, Tennessee, Stibitz stated that those who wanted a new computer were "the makers," who had "ideas about how a computer could be built," and "the users," who were "bothered by problems they hope[d] a computer might help to solve."[28] The latter category of people were not well-versed in mathematics or computing machinery but might develop an interest in these fields, and included amateur adult technology enthusiast who read scientific magazines and do-it-yourself (DIY) magazines and students who were unaware of computing machines and logic. This category was the primary target of Berkeley's firm. Berkeley strongly believed that magazines on computing machinery, for example, should not be understandable to only a handful of specialists.[29]

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[25] Edmund C. Berkeley, "Memorandum: E. C. Berkeley and Associates - Purpose," December 29, 1946. Box 15, Folder 1, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

[26] "Notice on Organization of an 'Eastern Association for Computing Machinery'," June 25, 1947. Box 8, Folder 57, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

[27] Edmund C. Berkeley, "Eight Hundred People Interested in Mechanical Brains," reprint, originally in *The American Statistician*, June-July, 1950. Box 15, Folder 75, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

[28] George Stibitz, "The Philosophy of Computing Machine Design," May 30, 1949. Box 8, Folder 58, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis. In this paper, Stibitz also mentioned the significance of "doodling" for inventors.

[29] Even in his later years, Berkeley severely criticized ACM publications for being too specialized. ACM's

Among the projects initiated by Berkeley himself and his firm, the target audience behind the creation of the ACM and publishing of the magazine *Computers and Automation* was the first category of people—"the makers" and "the users" of computing machines. *Computers and Automation* began as the quarterly magazine *Roster of Organizations in the Field of Automatic Computing Machinery* in September 1951, and it was renamed *Computing Machinery Field* in September 1952. The magazine was eventually renamed *Computers and Automation* in March 1953.[30] The publication of this magazine became the biggest source of income for his company from the early 1950s.[31]

In other projects, Berkeley interpreted the properties and performance of the computing machines, their possible applications in business, their social and ideological significance and the importance of logic. Berkeley headed various projects for education and the popularization of computing machinery such as the publication of reports, books, correspondence courses, demonstration of small machines or "robots" and sale of educational tinkering kits for those who fell into the second category. Berkeley resigned from Prudential in 1948 to work on these projects.

4. Berkeley as a "popularizer": publication of *Giant Brains*

The best-known mechanism that popularized the new computing machines was the publication of *Giant Brains; Or, Machines That Think*[32]—one of the earliest books on electric computing machinery. It described a large variety of the successful calculating machines from 1949 such as the IBM punch-card machine, MIT differential analyzer, Harvard Mark I and II, ENIAC and Complex Number Calculator. The explanations were meant for those who did not have extensive knowledge about computing machines, and the articles included information on the calculation procedure in each machine; the actions of parts such as relays and integrators; and newly invented memory storage such as the magnetic wire, delay line, and cathode tube. Technical terms and concepts were presented in a manner easily understood by a layperson. These explanations were quite detailed and precise because Berkeley collected information directly from the scientists and engineers who developed these machines, such as Samuel H. Caldwell, Grace Hopper, and George Stibitz[33]. Moreover Berkeley himself had worked on Aiken's Harvard Mark I and II and learned about the working of ENIAC and the differential analyzers at MIT through his

interview with Berkeley, VHS cassette, September 1988. Box 71, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

[30] Edmund C. Berkeley, "Project 152: The Magazine 'Computers and Automation'," August 7, 1954. Box 15, Folder 5, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

[31] "Operations and Projects," August 12, 1954. Box 15, Folder 5, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis. and "Annual Summary of Allocated Income and Expenses," 1961. Box 15, Folder 17, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis. In the 1940s, the actuarial consulting project was the primary source of income in Edmund C. Berkeley and Associates.

[32] Edmund C. Berkeley, *Giant Brains; Or, Machines That Think* (John Wiley & Sons, 1949).

[33] Edmund C. Berkeley, Note by Berkeley, on comments from Coldwell, 12 March 1947. Box 8, Folder 28, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis. and Edmund C. Berkeley, Note by Berkeley, on comment from Hopper, 27 March 1947. Box 8, Folder 28, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

experience in WWII and during the 1947 ACM meetings.[34]

Berkeley frequently used the terms "mechanical brain" and "electric brain" to describe a computing machine in *Giant Brains* and other articles. Historically, the expression "mechanical brain" or "electric brain" was used in the popular science magazine of the late 1920s to describe large analog machines.[35] By the 1930s, these terms were used in descriptions of the differential analyzer,[36] and once WWII broke out, they were used in that of gun directors.[37] After the war, in the middle of the 1940s, the Complex Number Calculator and ENIAC became termed as "brains."[38] Berkeley incorporated this contemporary usage and termed computing machines "mechanical brains" or "electric brains" and the large-scale computing machines, "giant brains." In *Giant Brains*, the articles emphasized that the machines called "brains" had not only the ability to calculate but also to reason. Unlike Warren McCulloch and Walter Pitts, who published "A Logical Calculus of the Ideas Immanent in Nervous Activity" in 1943 to propose a neural model as the linear threshold gate, Berkeley was not concerned with the physiological analogy between computing machines and brains. His regarding of computing machines as "brains" was simply based on the idea that machines could perform logical reasoning, especially the use of symbolic logic, as human brains do.

Giant Brains also published the descriptions of two non-practical small machines: Simon and the Kalin-Burkhart Logical Truth Calculator. Unlike other computing machines such as the Harvard Mark I, these machines were unknown to even those constructing or using computing machines at that time, and they did not have a large calculation capacity. They were simply small experimental machines and did not supply any actual computing demand. The reason why Berkeley chose these machines was to clearly demonstrate the relationship between computing machines and symbolic logic to first-time learners of the computing machines.

In the chapter 3 of *Giant Brains*, before introducing the practical computing machine, Berkeley describes a small machine named Simon. This machine "came into existence"[39]

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[34] In December 1947, a meeting of the Eastern Association for Computing Machinery was held at the Ballistic Research Laboratories, Aberdeen Proving Ground in order to learn about the collection of the laboratories, including ENIAC, the Bell relay computer, IBM sequence-controlled relay calculator, and the differential analyzer. (Edmund C. Berkeley, "Preliminary Announcement—Meeting at the Ballistic Research Laboratories, Aberdeen Proving Ground, on December 11-12, 1947," November 7, 1947. Box 8, Folder 57, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.)

[35] In "Mechanical Man—Our New Slave" (*Popular Science*, December 1928), an integraph made by Vannevar Bush was known as the "Great Brass Brain," because it "performs its thinking processes." The Tide Predicting Machine No. 2 was also termed a "Brass Brain" in the article "Brass Brain saves U. S. $125,000 yearly" published in *Modern Mechanix* (November 1928).

[36] For example, the differential analyzer and integrator were described in "Latest of 'Electric Brains' Solves Even Calculus" (*Popular Mechanics*, April 1932) and "'Mechanical Brain' Works Out Mathematical Engineering Problems" (*Modern Mechanix*, June 1932).

[37] For example, "Modernizing Our Coast Defense" (*Popular Mechanics*, January 1941), "Motorization and Mechanization Help the Army More Faster and Hit Harder", (*Popular Science*, August 1941), and "Wheels That Can't Slip", (*Popular Science*, February 1945).

[38] The Complex Number Calculator was described in "'Electric Brain' Solves Complex Problems by Long-Distance Wire" (*Popular Mechanics*, January 1941) and ENIAC, in "The Army Brain" (*Mechanix Illustrated*, June 1946).

[39] Edmund C. Berkeley and Robert A. Jensen, "How an Electric Brain Works, Part VI," *Radio Electronics*

when Berkeley had a conversation with Theodore A. Kalin at the meeting of the Association for Symbolic Logic in December 1947. When Berkeley wrote *Giant Brains*, Simon had been designed but not constructed. *Giant Brains* described "the purpose of" Simon as "being a simple introduction on paper to the same type of computing circuits used in the big mechanical brains"[40]; it was a machine that had relays, lights, a two-hole punched tape reader, and a four-hole punched tape reader[41] and that handled four numbers—00, 01, 10, 11—and four operations—"addition," "subtraction," "greater than," and "selection." Berkeley provided the basic knowledge on how to represent and store information in a computing machine through detailed explanations on the design of the circuits used in Simon or on the assignment of a punched-hole code to 16 memory registers. Moreover, it was emphasized that Simon could handle the "language" of mathematical logic.[42] The role of Simon in *Giant Brains* was plainly described as follows:

> It may seem that a simple model of a mechanical brain like Simon is of no great practical use. On the contrary, Simon has the same use in instruction as a set of simple chemical experiments has: to simulate thinking and understanding and to produce training and skill. A training course on mechanical brains could very well include the construction of a simple model mechanical brain as an exercise. In this book, the properties of Simon may be a good introduction to the various types of more complicated mechanical brains described in later chapters.[43]

The Kalin-Burkhart Logical Truth Calculator was introduced to explain that computing machinery had the potential ability to reason. According to the review by D. R. Hartree, the first mentions of the Kalin-Burkhart Logical Truth Calculator probably appeared in *Giant Brains*.[44] This machine could be, as Hartree mentioned, "regarded as a special case of a calculating machine,"[45] because it could handle logical operators. It was a small machine—16 inches tall, 13 inches deep and 30 inches long—and it contained 45 dial switches, 23 snap switches, 85 relays and 6 push buttons.[46] Construction of this machine was carried out from March to June 1947 by Kalin and William Burkhart, students of Harvard University at the time, in order to solve the problems they encountered in a symbolic logic class taught by W. V. Quine. This machine specialized in logical operation and was not useful for arithmetic calculation; it could deal with four kinds of connectives—AND, OR, IF-THEN and IF AND ONLY IF—and could calculate the truth values of complicated statements and create a truth table automatically. The logical oper-

(March 1951) in *Constructing Electric Brains*, reprinted by Edmund C. Berkeley and Associates, 1952. pp. 15–17. Box 21, Folder 55, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

40 Edmund C. Berkeley and Robert A. Jensen, "How an Electric Brain Works, Part VII," *Radio Electronics* (April 1951) in *Constructing Electric Brains*, reprinted by Edmund C. Berkeley and Associates, 1952. p. 21. Box 21, Folder 55, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

41 Edmund C. Berkeley, *Giant Brains; Or, Machines That Think* (John Wiley & Sons, 1949), p. 22.

42 Ibid. p. 26.

43 Ibid. p. 31.

44 D. R. Hartree, "Book Review: Giant Brains," *British Journal of Applied Physics*, 1950. Box 8, Folder 30, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

45 Ibid.

46 Edmund C. Berkeley, *Giant Brains; Or, Machines That Think* (John Wiley & Sons, 1949), p. 156.

ators were input by manipulating dial switches and snap switches, and a set of conditions were systematically checked in a relatively short time. Further, 128 cases for 7 conditions were processed in $1^1/_4$ minutes, and 256 cases for 8 conditions in $21^1/_2$ minutes.[47] Berkeley had attended a seminar by Quine in mathematical logic at Harvard from 1946 to 1947 and acquired the opportunity to learn about the Kalin-Burkhart Logical Truth Calculator.[48] He discovered that this machine could be used for drafting clauses and contracts in insurance companies, and he regarded the machine to be an excellent example of the practical application of symbolic logic and Boolean algebra. Kalin was invited to Prudential in September 1947 to demonstrate the use of this machine.[49] Eventually the Department of Methods at Prudential concluded a rent contract for the Kalin-Burkhart Logical Truth Calculator, and experiments for constructing a logical truth calculator for Prudential's laboratory were conducted by Berkeley at the methods department[50]. Berkeley even made a presentation about the calculator at the meeting of the Association for Symbolic Logic in December 1947. In *Giant Brains*, he assigned chapter 9 to this machine as well as the IBM punch-card machine, MIT differential analyzer, Harvard Mark I and II, ENIAC and the Bell Labs Complex Number Calculator. The reason why Berkeley introduced Simon and the Kalin-Burkhart Logical Truth Calculator, although they were small and impractical machines, was because he highly valued the logical capacity of computing machinery, and these two were good examples of machines that were capable of dealing with basic logical operators.

It is noteworthy that in the chapter on the Kalin-Burkhart Logical Truth Calculator in *Giant Brains*, Berkeley explicitly refers to Shannon's 1938 paper "A Symbolic Analysis of Relay and Switching Circuits,"[51] as the theoretical basis for the relationship between electrical circuits and logic. This paper was Shannon's thesis while pursuing his master's degree, and it was submitted to MIT in the summer of 1938 and published in *Transaction of AIEE* in 1939. In this paper, Shannon tried to clarify the mathematical properties of relay switching circuits used in the telephone switching system and control circuits. Shannon demonstrated how to analyze and synthesize complicated switching circuits by assigning the binary digits, 0 and 1, to open and break a relay and by applying Boolean algebra. It is often said that this paper not only enabled engineers to design the circuits theoretically but also affected the design of logical circuits in digital computing machinery.[52] However, this paper did not actually influence the foundation of computing machinery design in the 1940s; Shannon's work did not contribute to the development of digital computing

[47] Ibid., p. 166.

[48] Edmund C. Berkeley, "Record of Edmund Callis Berkeley", June 4, 1949. Box 8, Folder 32, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

[49] Edmund C. Berkeley, "Kalin-Burkhart Logical Truth Calculator—Demonstration," September 8, 1947. Box 4, Folder 1, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

[50] Edmund C. Berkeley, "Kalin-Burkhart Logical Truth Calculator - Renewal of Rental," March 9, 1948. Box 4, Folder 6, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

[51] Claude E. Shannon, "A Symbolic Analysis of Relay and Switching Circuits," *Transaction of AIEE*, vol. 57 (1938), pp. 713–723.

[52] For example, Martin Davis, *Engines of Logic* (Norton, 2000), p. 178; Howard Rheingold, *Tools for Thought*, revised edition, (MIT Press, 2000); and Gerard O'Regan, "Claude Shannon," in *A Brief History of Computing* (Springer London, 2012), pp. 209–218.

machinery in the late 1930s and 1940s. Only a few articles on the subject of computing machinery building projects in the 1940s and 1950s, including those on ENIAC, EDVAC, and the calculators at Bell Labs, referred to the paper. In addition, a mathematical analysis of switching circuits by using Boolean algebra was conducted not only by Shannon but by other scholars independently, for example Johanna Piesch and Akira Nakashima.[53] Nearly identical results were simultaneously presented, so that it is inappropriate to attribute the application of Boolean algebra to only Shannon. As Alonzo Church points out in a review of "Formal Logic and Switching Circuits" by Theodore A. Kalin in 1952:

> The author's statement that Shannon's paper of 1938 is the first exposition of the relations between "two-valued logic and switching circuitry" requires some qualification. It seems to be not generally known that the first suggestion of such a relationship was made in 1910 by Erénfést [...][54]

In short, research on switching theory and Boolean algebra was carried out by different scholars independently, and Shannon's work was not contextualized as computer machinery development. Berkeley, however, referred to Shannon's paper in this context because the paper seemed to aid in theoretically reinforcing Berkeley's idea on the relationship between computing machinery and symbolic logic.[55] Church made Berkeley aware about Shannon and his paper,[56] when the former two discussed the topic of Boolean algebra in December 1940. Berkeley acquired Shannon's address and requested a copy of the 1938 paper; moreover, after his meeting with Shannon at Bell Labs in 1941, he retained an intermittent association with Shannon for more than 20 years.

Berkeley's reference to Shannon's paper was probably one of the earliest cases the latter was mentioned in a publication on computing machines meant for the general public. Over 15,000 copies of *Giant Brains* were sold from the time of its first publication in November 1949 to 1958, and from 1960 to 1967, over 6,800 paperback copies were sold.[57] Berkeley reproduced the discourse that Shannon's 1938 paper provided the the-

[53] Attributing the first of analysis of electric switching circuits using Boolean algebra to one person has remained a controversial topic. According to Radomir S. Stankovíc, Jaakko T. Astola, Mark G. Karpovsky, "Some Historical Remarks on Switching Theory" (http://mark.bu.edu/papers/200.pdf.pdf, viewed August 31, 2010), this topic was explored and published in Russia in 1910, 1934, and 1935. As Paul Ceruzzi points out in *Reckoners*, (http://ed-thelen.org/comp-hist/Reckoners.html, viewed August 31, 2010), the analysis of electric switching circuits by binary notation was studied in Japan by Akira Nakashima in the late 1930s. (Akihiro Yamada, "History of Research on Switching Theory in Japan," *Transactions of the Institute of Electrical Engineers of Japan FM*, vol. 124, no. 8 (2004), pp. 720–726. (in Japanese.)) Nakashima's articles on this topic (only the Abstract is in English) were, however, published in February 1938, and Nakashima continued working at Bell Labs from 1939 to 1940. Therefore, it is difficult to imagine that Shannon referred to Nakashima's research or his paper before he submitted his master's thesis. It would be reasonable to think that the relationship between the relay circuit analysis and binary notation was studied in different places simultaneously.

[54] Alonzo Church, review of "Formal Logic and Switching Circuits" by Theodore A. Kalin, *The Journal of Symbolic Logic*, vol. 18, no. 4 (December 1953), pp. 345–346.

[55] Interestingly, Berkeley did not express an interest in the Alan Turing's famous theoretical work, which was connected to both the logic and structure of digital computing machinery.

[56] Alonzo Church, Letter from Church to Berkeley, December. 31, 1940. Box 1, Folder 39, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

[57] R. Hoffman, Letter from R. Hoffman to Berkeley, November 17, 1958. Box 8, Folder 40, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis. The number of paperback versions of *Gi-*

oretical basis for the relationship between computing machinery and symbolic logic in a number of publications in later years. For example, in "The Relations between Symbolic Logic and Large-Scale Calculating Machine" published in 1950, Berkeley described the characteristics of symbolic logic, such that it "studies mainly non-numerical relations" and "seeks precise meaning and necessary conclusions." In addition, Shannon's "contribution" to computer construction was clearly declared in this paper. Berkeley noted as follows:

> As a result of [the] work by Claude Shannon, Boolean algebra has proved to be useful in designing and checking electrical circuits using relays or electronic tubes. This application of symbolic logic is important in the design and construction of automatic computers.[58]

Correspondence courses provided by Berkeley Enterprises, a successor of Edmund C. Berkeley and Associates, also reflected Berkeley's own interests: the subjects were symbolic logic, language, computing machinery, cybernetics, construction of small robots, operations research, statistics, mathematics, and so on. Once again, we can observe Berkeley's focus on symbolic logic and computing machines. These correspondence courses were provided not only in the United States but also in South American and European countries. The entry fee for a course in 1951 was $15, and the course fees ranged from $28–$35.[59]

5. Berkeley's robots for demonstration and education

Another of Berkeley's firm's primary projects, apart from publication, was building of specific, albeit complicated, machines to be rented out for demonstration purpose. Berkeley recalled the following in 1963:

> [...] there are many educational possibilities with small robots, and the planning and understanding of circuits inside these machines (using relays which are just on and off devices) is a most useful and important introduction to logic, symbolic logic, Boolean algebra, and computers.[60]

What Berkeley termed as small robots were "small machine[s] that display intelligent behavior"[61] or "machines that respond to their environment and behave by themselves, or

ant Brains is not very large number, when compared to, for instance, *Cybernetics* by Norbert Wiener, which sold 21,000 copies und underwent three reprints in six months. (David Mindell, Jérôme Segal, and Slava Gerovitch, "From Communications Engineering to Communications Science: Cybernetics and Information Theory in the United States, France, and the Soviet Union," in *Science and Ideology: A Comparative History*, ed., Mark Walker (Routledge, 2003), p. 75.)

58 Edmund C. Berkeley, "The Relations between Symbolic Logic and Large-scale Calculating Machines," *Science*, vol. 112, October 6, 1950, p. 396.

59 Edmund C. Berkeley, Announcement of Courses by Mail, June 15, 1951. Box 30, Folder 12, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

60 Edmund C. Berkeley, Letter from Berkeley to Arthur W. Weeks, February 26, 1963. Box 22, Folder 23, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

61 Edmund C. Berkeley, "Memorandum from Edmund C. Berkeley and Associates, Project 105: Small Robots," August 12 1954. Box 21, Folder 60, Edmund C. Berkeley Papers (CBI 50), CBI, University of Min-

Figure 1. Berkeley demonstrates Simon; Courtesy of the Charles Babbage Institute, University of Minnesota, Minneapolis; Edmund Berkeley Papers (CBI 50), Box 71.

operate by remote control, or play games with people, etc."[62] A purpose of constructing the small robots was to rent them out for demonstrations in shows in order to generate advertising for a borrower company and Berkeley's firm; another purpose was to educate and train amateur technology enthusiasts and students. The small robots were used to illustrate the basic structure of computing or automatic machines.

One of the main robots built by Berkeley's firm was Simon. When Berkeley wrote about Simon in *Giant Brains*, it was a theoretical concept because a real machine had yet to be built. Simon's construction began in November 1949 and was completed in April 1950.[63] William A. Porter, a skilled engineer instrumental in the building of the Harvard Mark II, and Robert A Jensen, a student at Columbia University, were engaged in the construction.[64] In the first version, Simon "could handle only numbers 0, 1, 2, and 3 and four operations, addition (without carry), subtraction or negation (without carry), greater than, and selection." However, after some modification were carried out on Simon from July to September 1950, it could take "in numbers up to 255, and perform five additional

nesota, Minneapolis.

62 Edmund C. Berkeley, "Small Robots Report," April 1956. Box 38, Folder 48, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

63 Edmund C. Berkeley and Robert A. Jensen, "How an Electric Brain Works, Part VII," *Radio Electronics* (April 1951), in *Constructing Electric Brains*, Reprinted by Edmund C. Berkeley and Associates, 1952. p. 21. Box 21, Folder 55, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

64 Edmund C. Berkeley, "Simple Simon," *Scientific American*, vol. 138 (November 1950), p. 42.

operations: logical 'and', logical 'not' or three complement, logical 'or', addition subject to carry, and subtraction or negation subject to carry".[65] The size of Simon was 1 $^{1}/_{4}$ cubic feet, and it had about 130 relays,[66] over 1,000 soldering connections,[67] and weighed about 39 pounds. The parts cost $270[68] including the tape transmitter, which was $55, and the stepping switch, which was $15.[69] The cost of labor for wiring amounted to another $270.[70] Simon became well known through its appearance in *theWall Street Journal* on

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[65] Edmund C. Berkeley and Robert A. Jensen, "Construction Plans for Simon," second edition, March 1952. Box 22, Folder 22, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

[66] It is difficult to specify the precise number of relays in Simon because it had room for spare relays. According to the parts listed in the document "Construction Plans for Simon," there were 131 relays in Simon. However, an article that appeared in *Radio Electronics* (Edmund C. Berkeley and Robert A. Jensen, "How an Electric Brain Works, Part VI," *Radio Electronics* (March 1951), in *Constructing Electric Brains*, reprinted by Edmund C. Berkeley and Associates, 1952.), recorded the number of relays in Simon as 129. In *Scientific American* (Edmund C. Berkeley, "Simple Simon", *Scientific American*, vol. 138 (November 1950)), Simon has been described as having "120-odd relays (of which about 10 per cent are spares, available for increasing Simon's capacity)." In the picture of Simon on the front cover of *Scientific American*, Simon appears to have only 122 relays because the picture does not include the bottom row of 6 relays; moreover, it is difficult to notice the auxiliary stepping relay, which was placed next to the tape feeding unit.

[67] Edmund C. Berkeley and Robert A. Jensen, "Construction Plan for Simon," second edition, 1952. Box 67, Folder 44, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

[68] In *Giant Brains* (p. 21), Berkeley stated that a relay for calculating machines cost $5–$10. The relays for tinkering kits, however, were priced at roughly at $1–$2. For example, in an advertisement by Wells Sales, Inc. "Relays For Every Purpose Over a Million in Stock!" (*Radio Electronics* (October 1948), p. 98) the price of standard DC telephone relays for 24 volts was within the range of $1.10–$1.59. Only a few special relays, such as the DC-rotary step relay and adjustable time delay relay, were sold for around $10. Berkeley also looked for a way to buy relays at a low price. For example, when he tried to design the successor of Simon—Simon Half—Jensen informed him that Shannon said IBM sold its wire relays within its company for 24 cents ("Memorandum by Robert Jensen for Berkeley," Box 37, Folder 32, Edmund C. Berkeley Papers (CBI 50)). Berkeley even considered manufacturing small relays for toy kits at a fairly low cost because "for a toy, reliability though desirable is not essential" ("Simon Half: Confidential Memorandum for Associates: William A. Porter, Robert A. Jensen, and Andrew Vall from Edmund C. Berkeley," June 17, 1950. Box 37, Folder 32, Edmund C. Berkeley Papers (CBI 50)).

[69] Edmund C. Berkeley and Robert A. Jensen, "How an Electric Brain Works, Part VII," *Radio Electronics* (April 1951), in *Constructing Electric Brains*, reprinted by Edmund C. Berkeley and Associates, 1952, p. 21. Box 21, Folder 55, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis. In *Scientific American* article, the cost of the tape transmitter is listed as $50.

[70] Edmund C. Berkeley and Robert A. Jensen, "How an Electric Brain Works, Part VII," *Radio Electronics* (April 1951), in *Constructing Electric Brains*, reprinted by Edmund C. Berkeley and Associates, 1952, p. 21. Box 21, Folder 55, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis. Berkeley listed different costs for Simon in several papers. For example, in "Geniacs: Simple Electric Brain Machines, and How to Make Them" (Box 37, Folder 45, Edmund C. Berkeley Papers (CBI 50)), the materials for building Simon alone are said to cost over $300. According to the article in *Scientific American*, the wiring cost of $270 "does not include the cost of the designing and a good half of the labor, which was contributed, that is, the labor cost of Berkeley and Jensen would not be included in this wiring cost." In "Fact Sheet on 'Simon,' May 18, 1950" (Box 48, Folder 60, Edmund C. Berkeley Papers (CBI 50)), Simon costs "[a]bout $600," and "[t]he time and effort of the two Columbia students was contributed." The $600 would be a rough total of the cost of the parts and wiring by the students. Berkeley provided the total cost of Simon, including the cost of his and Jensen's labor. In "How an Electric Brain Works, Part VII," in *Radio Electronics*, the following is mentioned: "The balance of the labor, design, engineering, mechanical work, etc., was contributed; if it had been paid for, it [the total cost of Simon] would have amounted to about $3,000." According to "Valuation of Physical Assets as of Dec. 31. 1954" (Box 15, Folder 5, Edmund C. Berkeley Papers (CBI 50)), and "Small Robots Report, April 1956" (Box 38, Folder 48, Edmund C. Berkeley Papers (CBI 50)), the value of Simon was $4,000.

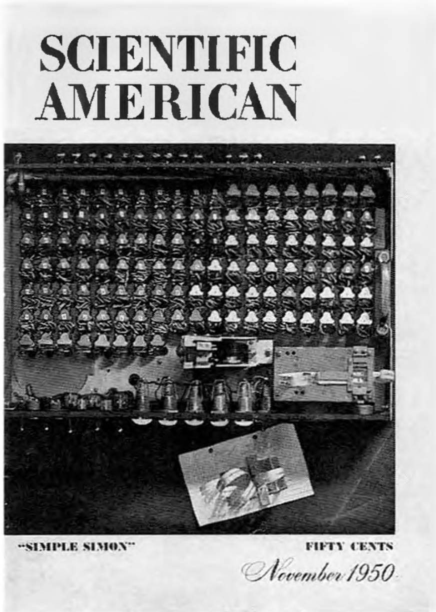

Figure 2. *Scientific American*, vol. 138 (November 1950).

May 22, 1950, *Radio Electronics* in October 1950,[71] and *Scientific American* in November 1950.[72] It was demonstrated in at least eight cities in the United States. After its appearance in magazines and the demonstrations, Berkeley received a number of requests for the plans of Simon. At first, seven sets of plans were sold for $35 apiece; however, Berkeley decided to create hundreds of sets of plans for sale at $5.50 apiece.[73] In all, about 400 sets were sold.

This machine was intended to be a "simple understandable form" of the computer, and its purpose was "to aid in explaining, lecturing, and teaching" or to be a form of "automatic computing machinery or mechanical brains."[74] Berkeley also described it as entertaining "just as a spinning toy gyroscope is both entertaining and instructive."[75] Simon's primary target audience was students: they could read articles on Simon, observe a demonstration of a real machine at a show, or acquire the construction plan to study the basic structure of computing machines. In fact, Berkeley utilized Simon while teaching the course "Digital

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[71] Edmund C. Berkeley and Robert A. Jensen, "World's Smallest Electric Brain, Part I," *Radio Electronics* (October 1950), in *Constructing Electric Brains*, reprinted by Edmund C. Berkeley and Associates, 1952, pp. 1–2. Box 21, Folder 55, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

[72] Edmund C. Berkeley, "Simple Simon," *Scientific American*, vol. 138 (November 1950).

[73] Edmund C. Berkeley, "Project 145: Publication of Reports" in "Berkeley Enterprises, Inc. – Prospectus; Second edition," July 1955. Box 15, Folder 5, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

[74] Edmund C. Berkeley and Robert A. Jensen, "Construction Plans for Simon," second edition, March 1952. p. 1. Box 22, Folder 22, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

[75] Edmund C. Berkeley and Robert A. Jensen, "World's Smallest Electric Brain, Part I," *Radio Electronics* (October 1950), in *Constructing Electric Brains*, reprinted by Edmund C. Berkeley and Associates, 1952, p. 1. Box 21, Folder 55, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

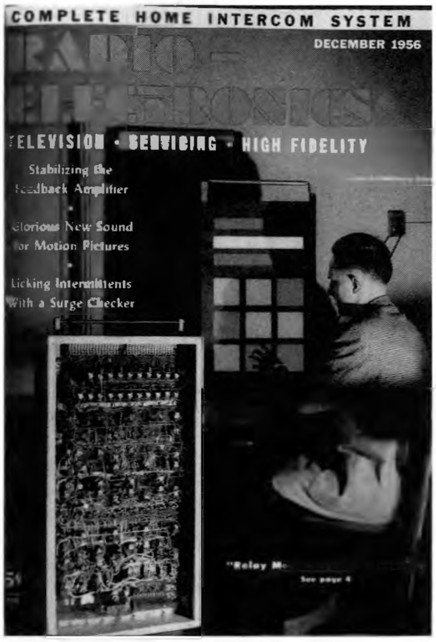

Figure 3. *Radio Electronics* (December 1956).

Computers and Techniques" at City College, New York, in the fall term of 1951–1952.[76]

Berkeley assembled several machines other than Simon in the 1950s. After constructing Simon, Squee—a robotic squirrel that could automatically pick up tennis balls—was constructed in around 1950. Berkeley published the building plans for Squee as well as Simon.[77] The next logical machine built by Berkeley was called the Relay Moe—an automatic relay machine that could play tic-tac-toe with a human opponent—and it was built to study the behavior of an "intelligent machine."[78] Relay Moe could perform nine arithmetic and logic operations and store one binary digit of information in 20 tracks; it also had several different strategies, including one where a human opponent could win.[79] Just like Simon, an article on Relay Moe was published in *Radio Electronics* in 1956, and it was rented over eight times by Berkeley Enterprises to companies and organizations. In addition to Simon, Squee, and Relay Moe, more than five complicated robots were designed and constructed by Berkeley Enterprises.[80]

Berkeley, however, was still bothered by the fact that almost all the machines were too expensive to be utilized by their target audience, particularly students and children. Even

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[76] Edmund C. Berkeley and Robert A. Jensen, "Construction Plans for Simon," second edition, March 1952, p. 1. Box 22, Folder 22, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

[77] Edmund C. Berkeley, "Squee, The Robot Squirrel Construction Plans," 1951. Box 67, Folder 48, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

[78] Edmund C. Berkeley, "An Earning Prospect for Berkeley Enterprises—A Small Automatic Computer to Do Useful Work," March 25, 1957. Box 21, Folder 60, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

[79] Edmund C. Berkeley, "Relay Moe Plays Tick Tack Toe," *Radio Electronics* (December 1956), pp. 50–52.

[80] Berkeley upgraded Simon into the larger machine "Simon IV" in the 1960s. Photographs, Box 71, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

if the audience got the plans for the machines, including those for Simon and Squee, the cost of the parts would make the real machine too expensive to build.[81] Berkeley found the solution: an electrical toy kit that was cheap and accessible to young students.

6. Collaborative work for electrical toy kits

Berkeley had planned to develop an inexpensive switching toy kit immediately after the completion of Simon in June 1950.[82] He tentatively named this "mechanical brain" toy set "Simon Half," which would be sold at the cost of $15 and would "not [cost] more than $3 to $5 to manufacture."[83] The kit was to contain basic and cheap parts: a wire, battery, battery clamp, panel, bulbs, sockets, nuts, bolts, switching disks, and so on. The switching disk was a substitute for the switching relay, which was easy to assemble without soldering. The planned kit was quite simple to construct and contained a number of parts, so that after working on and enjoying one experiment, the user could easily dismantle the composite circuit and rearrange the parts for another experiment. This kit was intended for school boys 10–14 years and older school students aged around 18 years. Berkeley felt that the consumer market for this type of toy kit was a rather big one;[84] he believed that such a kit would stimulate a scientific interest in students and children and help them deepen their understanding of "mechanical brains." This plan, however, had been suspended for several years. Berkeley restarted work on this idea in 1954 by initiating discussions with Shannon and his colleague, David Hagelbarger.

Since the early 1940s, Berkeley had maintained his correspondence with Shannon.[85] They both shared an interest in tinkering. As Berkeley built Squee and Relay Moe and developed a "good business out of an odd hobby,"[86] Shannon also built a number of game machines: for example, a chess-playing machine; a maze-solving machine "Theseus," on which a mechanical mouse solved a maze and remembered the route to the exit; a strategy board game machine named "Hex(Hox)" that had a trick and cheated a human player; and the roman numeral calculator "THROBAC (THrifty ROman numeral BAckwards-looking Computer)." Shannon's chess-playing and maze-solving machines appeared in articles and magazines such as *Life*.[87] Shannon built most of the machines at Bell Labs, and his colleague, Hagelbarger, who newly gained fame at Bell Labs with the invention of game

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[81] The cost of Squee's parts was $195. Edmund C. Berkeley, "Squee, The Robot Squirrel Construction Plans," 1951. Box 67, Folder 48, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

[82] Edmund C. Berkeley, *Brainiacs: 201 Small Electric Brain Machines, and How to Make Them* (Berkeley Enterprises Inc., 1959), p. 2.

[83] Edmund C. Berkeley, "Simon Half: Confidential Memorandum for Associates: William A. Porter, Robert A. Jensen, and Andrew Vall from Edmund C. Berkeley," June 17, 1950. Box 37, Folder 32, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

[84] Ibid.

[85] For example, Letter from Shannon to Berkeley, February 14, 1941. Box 1, Folder 39, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

[86] *Life*, March 19 (1956).

[87] Mai Sugimoto, "Claude Shannon's Maze Solving Machine: Transition of Its Interpretation in Bell Labs," *PHS Studies*, vol. 4 (2010), pp. 1–19 (in Japanese).

machines, sometimes collaborated with him. They even worked together on the writing of technical report about their machines, such as their mind-reading machine and Nim playing machine.[88] Shannon's machines had some implications related to telephony or the switching theory, since Bell Labs did not actively approve of experiments that had nothing to do with telephone technology.[89] One of the machines devised by Shannon and Hagelbarger for Bell Labs in 1954 was the relay kit for college students. In the technical report "A Relay Laboratory Outfit for Colleges, Jan 10 1954,"[90] they proposed an idea to provide relay kits to college laboratory courses for Bell Labs' "long-range policy," that is, to tutor future switching engineers. With this kit, which was built using relays from the real telephone switching system, students could easily study the circuit design by connecting a wire into the main plug board.[91] The kit could implement "the Perpetual Calendar"; "Morse coder, decoder"; and game playing circuits such as "Nim" and "Tower of Hanoi." Knowing that Shannon and Hagelbarger were familiar with building robots and kits, Berkeley asked them to work as consultants on his kit business, since they were surely the best partners to invent a new tinkering kit for students and children.

Discussions between Shannon, Hagelbarger, and Berkeley began in December 1954, and the consulting agreement was signed in early 1955.[92] Shannon and Hagelbarger's comments on the kit covered a wide range of areas; they even worked with Berkeley on the marketing of the kit, suggested experiments for customers, and discussed the various parts of the kit and its cost.[93] However, the consulting primarily focused on the design of experiments that could be performed using the kit. They proposed a number of experiments such as an "Adder," "Multiplier," "Morse encoder and decoder," "Combination lock," "Burglar alarm," "Nim machine," and "Tic-tac-toe machine." Most of the experiments were included in Shannon and Hagelbarger's 1954 paper titled "Relay Laboratory Outfit" or the paper "The 3-Relay Kit."[94] In addition, some of their suggestions were related to their past works. For example, "the Secret coder and decoder," which was eventually adopted in Berkeley's kit, was an experiment to encipher and decipher massages using the Ceaser's code,[95] which was also presented in Shannon's previous work on cryptogra-

[88] A collection of Shannon's robots is now preserved at the MIT museum. The papers on these robots can be found in *Claude Elwood Shannon Collected Papers*.

[89] Claude E. Shannon, Letter from Shannon to Rippenbein, April 11, 1949. Box 1, Folder 3, Papers of Claude Elwood Shannon (MSS 84831), Library of Congress.

[90] Claude E. Shannon and D. W. Hagelbarger, "A Relay Laboratory Outfit for Colleges," June 10, 1954, *Claude Elwood Shannon Collected Papers*, eds., N. J. A. Sloane and A. D. Wyner (IEEE Press, 1993), pp. 715–726.

[91] Edmund C. Berkeley, Memorandum about meeting with Claude Shannon, December 3, 1954. Box 37, Folder 42, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis. The kit was suggested as a commercial opportunity for Western Electric.

[92] Edmund C. Berkeley, Letter from Berkeley to Shannon and Hagelbarger, June 25, 1955. Box 37, Folder 42, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

[93] Edmund C. Berkeley, Memorandum about meeting with Claude Shannon, December 3, 1954. Box 37, Folder 42, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis. and Edmund C. Berkeley, Memorandum about meeting with Claude Shannon, December 31, 1954. Box 37, Folder 42, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

[94] Claude E. Shannon, "The 3-Relay Kit," n.d. Box 11, Folder 17, Papers of Claude Elwood Shannon (MSS 84831), Library of Congress.

[95] Edmund C. Berkeley, *Brainiacs: 201 Small Electric Brain Machines, and How to Make Them* (Berkeley

phy in the 1940s.[96] Furthermore, Shannon and Hagelbarger shared Berkeley's enthusiasm for Boolean algebra and binary notation. Hagelbarger noted the following in his handwritten memorandum in February 1955:

> Solution of Experiments on Binary Arithmetic and computer coding
> "This is the way the 'Giant Brains' calculates" etc etc [sic]
> you should be able to write this introduction so that it has glamour appeal to the brighter kids. It will also generate a future market for more advanced kits.[97]

Berkeley also learned of their plan for the rather advanced "3-Relay kit" and promised to help them move their plan forward, if they decided to endeavor to build it.[98]

Consequently, in the completed toy kit—named "Geniac" —more than 10 experiments out of 33 were created as a direct result of their consulting work. The Geniac kit—an abbreviated form of "Genius Almost-Automatic Computer"—was apparently named after other famous large-scale electrical computers. Geniac consisted of a wire, panel, 6 switching tables that could rotate to switch contacts, 10 flash lamps, and so on, and could be easily assembled and disassembled for the 33 possible experiments. A manual explaining how to assemble the parts for each experiment was attached to the kit.[99] The manual did not list the names of experiment designers, but the name "Claude Shannon" appeared many times in it because a part of Shannon's 1938 paper was mentioned in the explanation of the relationship between switching circuits and Boolean algebra. Even a reprint of Shannon's 1938 paper, "A Symbolic Analysis of Relay and Switching Circuits," was enclosed in the kit as an advanced teaching material. This was because, in 1952, Berkeley Enterprises acquired the rights to reprint the paper, and they continued to reprint it until at least 1959. Berkeley believed that the theoretical foundation of the Geniac kit was based on Shannon's early work. For Berkeley, Geniac was a small "mechanical brain" or "electric brain"[100] —an elemental small reasoning machine.

Unfortunately, Berkeley had to encounter a troubling situation. Owing to bankruptcy, the manufacturer of the Geniac kit established his own firm and sold another "Geniac" kit without seeking Berkeley's permission.[101] Therefore, Berkeley was compelled to devise other kits such as Tyniac and Brainiac. The Tyniac—"Tiny Almost-Automatic Computer" —entered the market in December 1955, soon after Berkeley's trouble with Geniac's man-

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Enterprises, Inc., 1959), p. 35.

96 Claude E. Shannon, "Communication Theory of Secrecy Systems," October 1949, *Claude Elwood Shannon Collected Papers*, eds., N. J. A. Sloane and A. D. Wyner (IEEE Press, 1993), pp. 84–143.

97 David Hagelbarger, Memorandum for Berkeley, February 14, 1955. Box 37, Folder 42, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

98 Edmund C. Berkeley, Letter from Berkeley to Shannon and Hagelbarger, June 25, 1955. Box 37, Folder 42, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

99 *Geniacs Manual*, 1955. Box 37, Folder 45, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

100 *GENIAC: Electric Brain Construction Kit No. 1,* 1955. Box 37, Folder 45, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

101 Edmund C. Berkeley, Memorandum for J. B. Felshin, June 8, 1958. Box 38, Folder 41, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

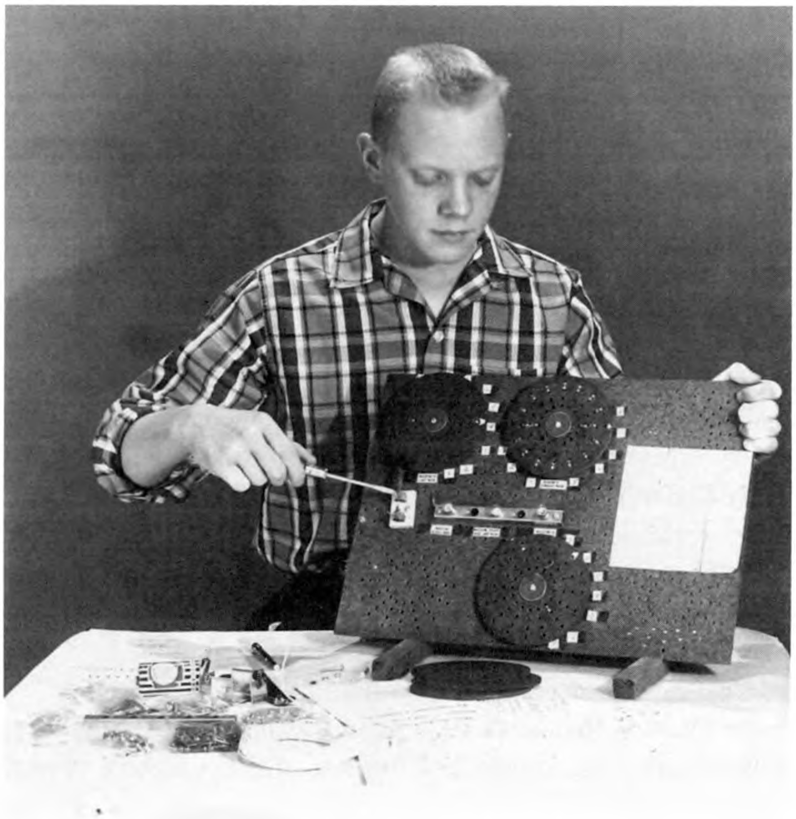

Figure 4. Brainiac Kit; Courtesy of the Charles Babbage Institute, University of Minnesota, Minneapolis; Edmund Berkeley Papers (CBI 50), Box 71.

ufacturer. Tyniac was developed as a "smaller, simpler and better kit"[102] than Geniac, and it contained 4 switching discs and 4 flashlights for 13 experiments. In the Tyniac manual, the last chapter contained experiments from which customers could study Boolean algebra through the building of switching circuits. The manual emphasized that Boolean algebra was "a new kind of algebra," which was "one of the best approaches" for the design of switching circuits;[103] it also noted that Shannon discovered that Boolean algebra could be applied to switching circuits.[104] According to Berkeley, Boolean algebra "is a useful and powerful tool" and people would "doubtless find out and learn more and more interesting and important applications of Boolean algebra as [they] become more and more accustomed to regarding AND, OR, and NOT as operators for calculating with, much like the operators PLUS, MINUS, TIMES, and DIVIDED BY."[105]

Brainiac—"BRAIN-Imitating Almost-Automatic Computer"—was sold in 1957, after Berkeley and Berkeley Enterprises decided to modify Geniac, which had been designed

[102] *Tyniacs Manual*, 1956, p. 5, Box 37, Folder 60, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

[103] Ibid., p. 6.

[104] Ibid., p. 42.

[105] Ibid., p. 46.

as a fun-game device, into a training device.[106] Brainiac was developed as a comprehensive kit, incorporating Geniac and Tyniac. The Brainiac kit had more than 450 parts, including 6 switching discs and 10 flashlights. Each switching disc had 65 holes to fasten a bridging conductor. In addition to the 33 experiments of Geniac and the 13 of Tyniac, 155 new experiments were suggested for Brainiac by 1959 in the attached, thick manual. Brainiac, of course, aimed at educating people about the basic structure of logical circuits that could be used in computing machines and the popularizing of Boolean algebra; even "A Simple Kalin-Burkhart Logical Truth Calculator" could be constructed using the Brainiac kit. Berkeley stated in a personal note that "each one teaches something new and useful about electrical computing and reasoning circuits" and "[o]ne section of the manual includes a careful introduction to Boolean Algebra."[107]

These Geniac, Tyniac, and Brainiac kits, through the use of which customers could learn how to organize elementary logical circuits, entered the market of electric hobby kits for youth. At the time, the market mainly consisted of radio, ham, and hi-fi, and the main target of the market were teenager and young men who preferred electrical engineering and worked (or liked to work) in it. For example, in January 1955, *Popular Electronics* carried an article titled "Hobby Kit Teaches Children Basic Electronics," which stated that "The how's and why's of basic electronics are unfolded for youngsters in a new educational hobby kit manufactured for 'Industrial America', Inc. by the Radio Corporation of America."[108] The September 1955 issue of *Popular Electronics* published an article titled "Your career in Electronics: Technical training is the key to many well-paying positions".[109] In 1959, *Electronics Kits*, a separate volume of *Popular Electronics*, carried the article "Why build kits?" According to this article, "First of all, you can save money with kits," "[s]econd, you can learn in a painless way, many of the secrets of electronics," and "kits provide a fascinating hobby that gives concrete results for both you and your family."[110] Berkeley's kit advertisement appeared in well-known hobbyist magazines including *Popular Electronics*; moreover, from among all the advertisements for radio, ham, and hi-fi, Berkeley's logical circuit kits were unique. A few kits, other than Berkeley's, were also labeled "computer", but Berkeley's kits were clearly education-oriented. The kits were aimed at studying the basic circuits used in electric computers, so that they were quite non-practical, when compared to the "practical" radio, amplifier, and ham kits. Even in 1959, a certain number of "computer" kits appeared in hobbyist magazines, and they were relatively expensive. For instance, a "computer" kit named "Model TR-1 Transistor Digital Experimental Kit" and sold Electronic Brain Enterprises Inc. cost $58.50.[111] The Brainiac kit was sold for a rather reasonable price, about $20, that made it accessible to young customers. In 1958, Brainiac was selected as the "Device of Enrichment Topics"

[106] L. Hewitt, "Letter from Lee Hewitt to Berkeley, Geniac Manual Revision," June 30, 1957. Box 38, Folder 15, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.
[107] Edmund C. Berkeley, "A Personal Note on Brainiac," n.d. Box 38, Folder 33, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.
[108] *Popular Electronics*, vol. 2, no. 1 (January 1955), p. 50.
[109] *Popular Electronics*, vol. 3, no. 3 (September 1955), pp. 29–32.
[110] *Electronics Kits: The Builder Guide and Directory* (1959), pp. 10–11.
[111] Ibid., p. 149.

in a pamphlet on "Teaching Aids" for mathematics teachers, published by the Teaching Aids Subcommittee of the Secondary School Curriculum Committee.[112] More than 10,000 copies of Brainiac, including a reprint of Shannon's 1938 paper, were sold in a year[113] and introduced into the field of education. Berkeley's purpose for educating and lecturing was accomplished, at least partly, by the Brainiac kit. It was sold until the late 1960s.

The collaboration between Berkeley and Shannon did not conclude with the building of Brainiac. Berkeley also designed a probability and statistics kit, named "Probability and Statistics Lab" along with Shannon and consigned it for sale to a firm named Science Material Center, which dealt with science-teaching material. Shannon, who was an expert in statistics, helped Berkeley once again, although the former "resolutely [did] not want [Berkeley and Science Material Center] to use his name."[114] Over 15,000 copies of this kit, which contained dice and an experimental kit for normal distribution, were sold by the Science Material Center.[115] After Brainiac and the Probability and Statistics Lab kit, Berkeley shifted the core of his activity to book publication, development of the programming language LISP and the peace movement.

7. Conclusion

Berkeley's business included various activities such as the publication of books and magazines, offering of correspondence courses, and building of electrical toy kits and robots for demonstration. These activities were aimed at teaching people about logic and circuits, because Berkeley enthusiastically followed his sense of a mission that the importance of symbolic logic and the detail of computing machinery, which would be the basis of the future society, should be better understood. Berkeley carefully devised each project so that the target audience would be properly instructed and the relationship between symbolic logic and the structure of computing machines would be popularized. In addition, Berkeley continued to publicize the achievements of Shannon for over 20 years through his business in popularizing symbolic logic and new high-speed computing machinery. While Berkeley's activities in ACM and *Computers and Automation* were for those who used or liked to use computers, most projects in his firm were aimed at those who did not know much about computers, both the young and old. Using his own business, Berkeley tried to be a popularizer and an educator of the new field of computers for primarily non-professionals.

112 Letter from the National Council of Teachers of Mathematics, December 12, 1958. Box 38, Folder 59, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

113 Edmund C. Berkeley, Letter from Berkeley to Nagourney, January 18, 1960. Box 61, Folder 53, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

114 Memorandum for Herb Nagourney from Ed Berkeley; Copy to Claude Shannon, September 8, 1960. Box 61, Folder 59, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

115 "Probability Statistics Kit Sells Record," November 1, 1962. Box 62, Folder 11, Edmund C. Berkeley Papers (CBI 50), CBI, University of Minnesota, Minneapolis.

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